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14. ABSTRACT

Also called Human-Centered Computing, this multidisciplinary field exploits advances in cognitive research together with those in computer science and related areas to optimize the cognitive, perceptual, and/or physical performance of experts and expert teams and the information systems that support them. The work extends that conducted under previous ONR funding for Human Systems Technology. It is focused in particular on (1)tactile interfaces for sensory substitution or augmentation in complex tasks; (2) advanced algorithms for Knowledge Discovery and Data Mining (KDD) and improved human abilities to recognize causal relationships; (3)studies of the trustworthiness of agents through a theory of adjustable autonomy; and (4) fundamental studies of exoskeletons for human performance enhancement. The work in each of these areas reflects the growing appreciation for the enormous potential that information technology has to leverage and amplify human capabilities. Realization of this potential requires a deep understanding of human cognition, perception, and/or locomotion; the relevant areas of computer science; and the nature of the human activity to be enabled. This inherently multidisciplinary approach to realizing the full potential of emerging information technology capabilities is at the heart of the Institute for Human and Machine Cognition (IHMC) and the research conducted during FY 2005.

15. SUBJECT TERMS

Artificial Intelligence, Human-Centered Computing, Augmented Cognition, Tactile Sensory Substitution, Exoskeletons, Human Performance Enhancement, Human-Agent Teamwork, Mixed-Initiative Human Control, Agile Computing, Knowledge Discovery and Data Mining

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FINAL REPORT FOR

"HUMAN-SYSTEM TECHNOLOGY"

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INTRODUCTION

The Institute for Human and Machine Cognition (IHMC) is pleased to submit a report of progress on the project Human Systems Technology for the 2005 fiscal year. This fiscal year work actually began on May 1, 2005 and was completed on July 31, 2006. Also called Human-Centered Computing, this multidisciplinary field exploits advances in cognitive research together with those in computer science and related areas to optimize the cognitive, perceptual, and/or physical performance of experts and expert teams and the information systems that support them. The work reported herein extends that conducted in the previous increment of ONR funding for Human Systems Technology. The FY 2005 work focused in particular on (1) psychophysical studies of tactile interfaces for sensory substitution or augmentation in complex tasks; (2) continued development of advanced algorithms for Knowledge Discovery and Data Mining (KDD) from large data sets and associated investigations of displays and training principles to improve human abilities to recognize causal relationships; (3) fundamental studies of the trustworthiness of agents through a theory of adjustable autonomy; and (4) fundamental studies of exoskeletons for human performance enhancement. The work in each of these areas reflects the growing appreciation for the enormous potential that information technology has to leverage and amplify human capabilities. Realization of this potential requires a deep understanding of human cognition, perception, and/or locomotion; the relevant areas of computer science; and the nature of the human activity to be enabled. This inherently multidisciplinary approach to realizing the full potential of emerging information technology capabilities is at the heart of the Institute for Human and Machine Cognition (IHMC) and the research conducted during FY 2005.

In what follows the progress made in each of these areas in FY 2005 is described. In each area we shall describe the objective of the work, the approach taken, a concise progress statement, an expanded description of progress, and, where applicable, lists of publications, awards, patents, and technology transfer activities.

PSYCHOPHYSICAL STUDIES OF TACTILE INTERFACES FOR SENSORY SUBSTITUTION OR AUGMENTATION IN COMPLEX TASKS

Scientific and Technical Objectives

Tactile interfaces have been developed for sensory substitution applications such as aids for the vision or hearing impaired. Tactile interfaces have also been developed for sensory augmentation in complex dynamic environments such as aviation applications. In the former application great effort is taken to represent the sensory information in as high resolution as possible (e.g., to let the operator "see" detail with the sense of touch.) The latter application seeks to reduce the resolution to the most basic useful tactile representation of particular sensor information in order to reduce the cognitive workload of understanding relevant information. In their current incarnations, both methods operate

without competition for sensory or cognitive assets, as little other tactile information is useful in their respective operational environments.

In 1995, the Naval Aerospace Medical Research Laboratory (NAMRL) and the Florida Institute for Human and Machine Cognition (IHMC) began collaborating on flight-testing NAMRL's Tactile Situation Awareness System (TSAS). Demonstrations have been conducted with a suit that provides pilots with spatial orientation information via tactile stimulation in order to reduce the number of SD accidents occurring with pilots. The suit was successfully flight tested on a blind folded pilot of a fixed-wing (T-34) aircraft and on several blind folded pilots of a rotary-wing (UH-60) aircraft. The UH-60 pilots successfully flew basic instrument tasks including unusual attitude recovery and in the T-34, the pilot successfully flew acrobatic flight maneuvers in addition to instrument flight tasks. Subsequent work has shown the effectiveness of this approach to unmanned aerial vehicle (UAV) control.

High-resolution tactile displays can only be effective if the areas they contact are highly innervated. Mapping of sensitivities has shown that the highest resolution of innervation occurs in the hands, face and tongue. In the aviation environment the tongue makes for an ideal location for a high-resolution tactile interface. Unlike the hands it is not in active use, except during verbal communications, and it has no keratinized skin layer, allowing for more efficient transduction of the tactile signal. We proposed to use our tongue based tactile interface to provide higher resolution information in concert with the lower resolution information of TSAS. This would represent a confluence of two tracks of thought on tactile displays, one of providing sensory augmentation displaying intuitive, dimensional/ directional information (as with TSAS) and the other of sensory substitution where information normally perceived via the eyes or ears is perceived through a tactile interface. The goal of this integration will be to create a tactile interface that operates, in 3D, in a manner similar to the eye, with low resolution "peripheral" sensation provided on the torso by TSAS and high resolution "foveal" sensation provided on the tongue, forming a "haptic retina". The resultant multi-faceted tactile display is being tested in concert with visual and audio displays using a fixed base simulator at IHMC.

Approach

We evaluated the effectiveness of the TSAS interface and developed the software infrastructure necessary to manage the information flow across multi-sensory (e.g., visual, auditory and tactile), multi-resolution (i.e., low and high) displays. We performed a series of experiments to test, evaluate and refine the effectiveness of multi-modal displays in dynamic environments.

Concise Progress Statement

The effectiveness of the TSAS torso tactile interface for learning a complex dynamic task was tested with experienced active duty Air Force test pilots (n=14) and novices (n=27). Both populations used the fixed base simulator at IHMC running a dynamically accurate simulation of the US Space Transportation System ("Space Shuttle") and both were able

to perform the space shuttle approach and landing skills more effectively when using TSAS than when using only the visuals provided by the simulation. This task requires a dead-stick landing with an aerospace craft that has poor aerodynamic handling characteristics. The frequency response to a moving target with multisensory displays was evaluated and IHMCs Adaptive Multiagent Integration (AMI) architecture was extended and leveraged to support multimodal displays, intelligent information scheduling and to provide the basis for the proposed "haptic retina".

Expanded Description of Accomplishments

We integrated our Adaptive Multiagent Integration (AMI) architecture, developed under funding from DARPA, with our tactile interface devices (the TSAS torso tactile interface and BrainPort™) to facilitate integrated testing. Delivery of a second generation version of the Wicab BrainPort™ was delayed approximately 1 year due to design and manufacturing issues and prevented us from fully testing our integrated high and low resolution tactile display concept. However, the new BrainPort™ has been integrated with TSAS and initial testing of the combined system is working as expected. Custom torso tactile interface hardware fabricated in FY04 has been revised to improve discrete control of the torso tactile interface and to enable use of intelligent automation features made available through integration with AMI. Two journal articles have been drafted describing the results of the FY04 experiments. A single article will be submitted that incorporates the findings of the studies conducted during FY05.

The pilot studies included a dynamic tracking task based on the Space Shuttle Heads Up Display (HUD) approach and landing deviation display using the poor ergonomics of the shuttle rotational hand controller (RHC) joystick. In the first condition, the guidance and velocity vector icons were driven in a pseudorandom fashion using the sum of 5 sinusoidal waveforms (0.04, 0.08, 0.12, 0.16 and 0.22 Hz) in the X and Y axes. The subjects were instructed to use the rotational hand controller joystick to keep the two icons superimposed. A second condition used surround sound (visual screens were blank) to provided the directional error between the two data points (driven by the same sinusoids,) and a third condition provided the subjects with the same deviation display using TSAS. Four more conditions that represented combinations of visual, audio and tactile stimuli were presented in a counterbalanced fashion. Fourier analysis was performed to determine the gain and phase for each display modality combination at the tested stimulus frequencies (see Figure 1).

The analysis demonstrates that the tracking task was sufficiently difficult, even at relatively low frequencies, to induce large pilot induced oscillations (large gains with phase shifts). Given that the task was based on a visual tracking paradigm, it is not surprising to see that the visual-only presentation provided the best response in gain (both axes). The multi-modal display (visual+audio+tactile) is however the next best across the majority of the frequencies tested. It is obvious from the data that the high frequencies in this task were too fast for accurate tracking. Follow up studies will focus on the range from 0.04 to 0.1 Hz to better characterize where the transition to an over compensation response arises. Additionally, we will investigate the tracking response to single
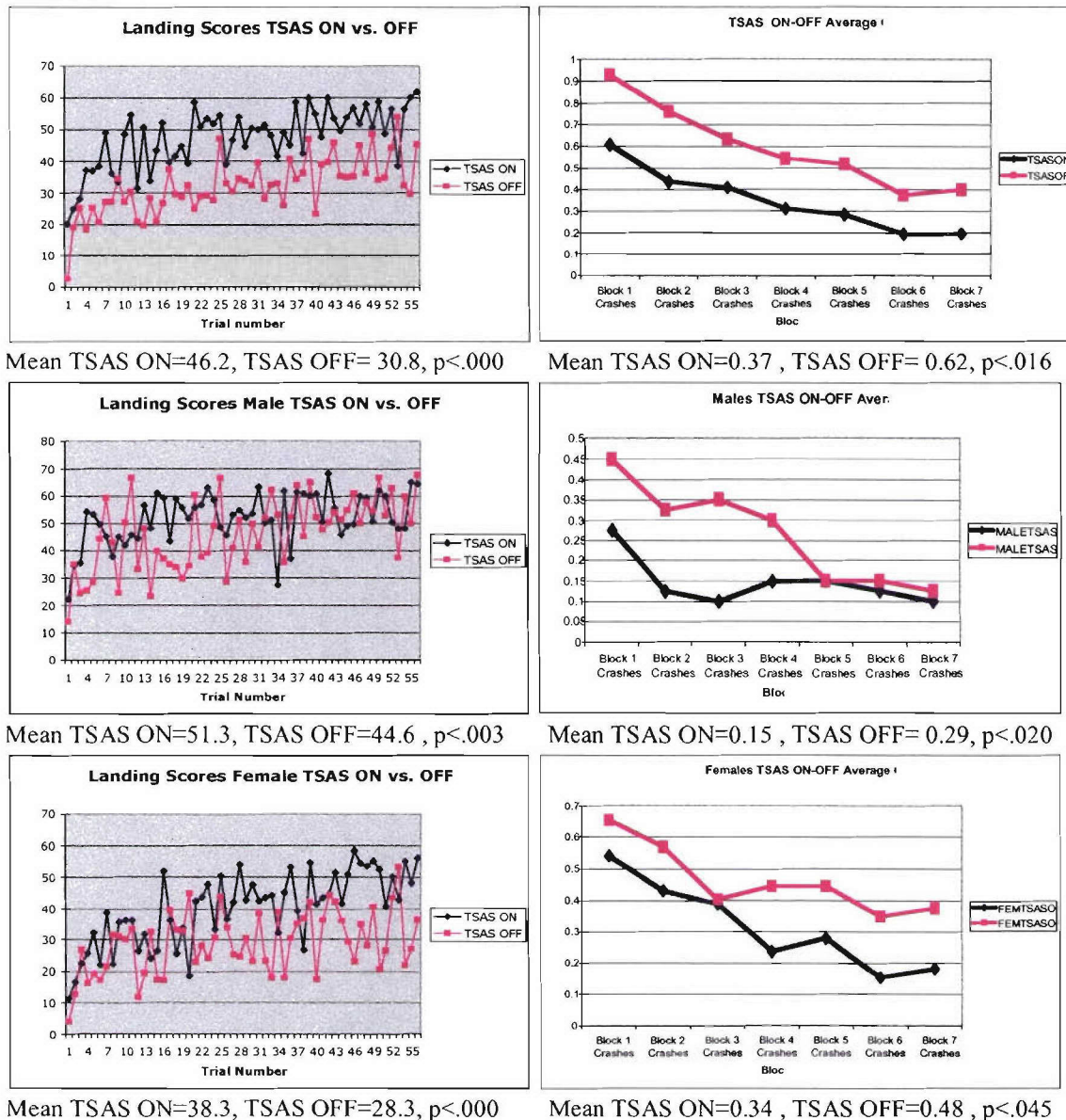
frequency sinusoids to verify that the pseudorandom nature of the tracking task did not adversely affect individual performance.
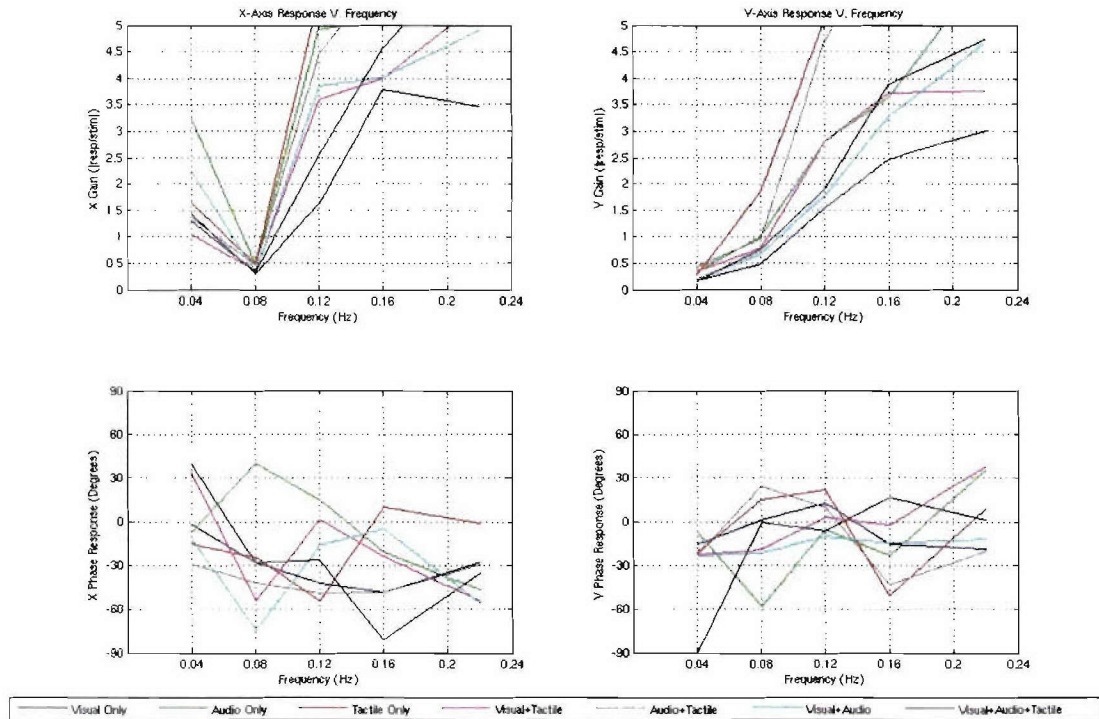
Figure 1: Bode plots for the seven pilot study conditions. Gain of 1 and phase lead/lag of 0 degrees are ideal.

For our evaluation of the performance of novices in the conduct of a complex task, we completed testing of 27 subjects in a simulated instrument landing system (ILS) final approach and landing in a fixed base simulator using the NASA Ascent-Entry Trainer/Cockpit Avionics Prototype Environment space shuttle simulation. All subjects were non-pilots and had never performed instrument flight or experienced ILS training. Each subject's performance with and without the tactile display was characterized by a NASA-JSC derived Justiz Numeric Measure (JNM) landing score. The maximum possible JNM score is 100 for perfect performance, and a crash results in a score of zero. The landing score or JNM was significantly improved by the presence of the tactile display. For all subjects the JNM was 46.2 with the tactile display compared to 30.8 without it ($p<.000$). In addition, the control group crashed 62% of the time while the tactile group only crashed 37% of the time ($p<.016$). Work to combine a low-resolution tactile display (torso) with a high resolution one (tongue) involved developing a Java software agent interface for the tongue display that allows single or multiple tactile elements to be activated with the following characteristics: azimuth, elevation and range (egocentric) as well as amplitude and "irritability". Additionally, custom hardware has been designed and fabricated to allow more discrete control of the torso tactile interface than previously possible.

Analysis of the JNM landing scores supports the gender differences noted by Kennedy et al, (1996) with the male group consistently scoring higher (male average=47.96, female=33.31, p<.000) and crashing less often (male average=28.6%, female average= 47.7%, p<.009). Due to this difference, data was analyzed by gender (male/female) as well as by group (test/control).

Mean TSAS ON=46.2, TSAS OFF= 30.8, p<.000   Mean TSAS ON=0.37 , TSAS OFF= 0.62, p<.016

Mean TSAS ON=51.3, TSAS OFF=44.6 , p<.003   Mean TSAS ON=0.15 , TSAS OFF= 0.29, p<.020

Mean TSAS ON=38.3, TSAS OFF=28.3, p<.000   Mean TSAS ON=0.34 , TSAS OFF=0.48 , p<.045

Figure 2: Landing score and number of crashes by trial (or block of trials) for TSAS vs. control, demonstrating gender difference.

A second study performed with the same simulator with active duty Air Force test pilots as subjects (N=14) who flew the approach and landing in reduced weather conditions and partial head up display (HUD) failure starting from 50,000 ft altitude demonstrated that JNM landing performance scores improved when tactile cues was added following initial

training (p< .01). From the data it is clear that TSAS allows novice subjects to achieve a higher level of performance when learning a novel complex task. This supports anecdotal evidence from prior TSAS studies where students claimed that they would be able to learn complex flight tasks more quickly when using a tactile interface.

Publications, Awards, and Patents

Peer-Reviewed Journal Articles

Raj, A. K., Higgins, J., Abraham, L. J., Carff, R. W., & Rupert, A. H. (in preparation). An application of the tactile situation awareness system (TSAS) to the learning of a complex dynamic task – ILS approach and landing.

Abstracts/Presentations/Posters/Conference

Raj, A. K., Higgins, J., Abraham, L. J., Carff, R. W., & Rupert, A. H. (2004). An application of the tactile situation awareness system (TSAS) to the learning of a complex dynamic task – ILS approach and landing, *Aerospace Medical Association 75th Annual Scientific Meeting*, Anchorage AK.

Olson, J. M., Raj, A. K., Thomas, R. E. and Davis, J. A. (2004) Tactile Display Landing Safety, Situational Awareness, and Workload Reduction Improvements for the Space Shuttle. *Aerospace Medical Association 75th Annual Scientific Meeting*, Anchorage AK.

Awards/Honors/Invention Disclosure

Aerospace Medical Association, Space Medicine Branch Young Investigator Award (best paper): Olson, J. M., Raj, A. K., Thomas, R. E. and Davis, J. A. (2004) Tactile Display Landing Safety, Situational Awareness, and Workload Reduction Improvements for the Space Shuttle (submitted to Aerospace and Environmental Medicine).

ADVANCED ALGORITHMS FOR HUMAN SYSTEMS TECHNOLOGY: Knowledge Discovery and Data Mining and Human Causal Learning

Scientific and Technical Objectives:

Our objective for this project was to expand the available suite of algorithms for data understanding—including procedures for classification and recognition, and procedures for inferring mechanisms from observed data, and procedures for reasoning with uncertainty--by mathematical work, computational implementations, and testing on real and simulated data. To these ends, we developed graphical algorithms for classifying a target in data sets with very large numbers of variables but comparatively few observations, and algorithms for identifying command and control sub-networks within

much larger communication networks. We also improved both foundations and implementation of algorithms for correcting noisy data—data polishing—and for estimating causal relationships, and we explored the structure of non-monotonic reasoning with probability bounds.

Approach

Our approach has been to focus on problems that are potentially pertinent to Navy and other Defense Department data analysis problems but are conventionally held to be too difficult for a principled solution to be possible. For example:

- Automated specification of causal relations from uncontrolled samples
- Locating a minimally sufficient set of predictor variables for a target variable when the number of variables far exceeds the sample size.
- Both of the above when the data are from distinct data sets with no cases in common (or no identified cases in common) and with distinct but overlapping sets of variables.
- Finding errors in data without presuming a model of the data generating process
- Clustering measured variables into groups sharing an unmeasured common cause, and extracting information about the causal relations among those unmeasured variables.
- Extracting command and control networks from data bases of communication logs, without knowledge of the language of communication.

In each case we have reconceived the problem, pursued formal work on algorithms, implemented the procedures, and tested them on simulated, and where available to us, appropriate real world data.

In addition we have considered theoretical problems of automated reasoning, based on interval estimates of probabilities and their propagation through courses of inference. Finally, we have attended to some fundamental issues in cognitive psychology, especially theories of human categorization, which seem pertinent to Defense Department problems.

Concise Progress Summary

Our major accomplishments this year included the design, implementation in JAVA, and testing of an algorithm for extracting command, control and reporting networks from communication logs. Other major work completed this year is a classification using graphical models of almost all current psychological theories of human category judgment. The representation enables us to systematically understand logical relations among the theories and to devise experiments to differentiate among them.

# Expanded Description of Accomplishments

One way of viewing the work on communication networks is as a classifier algorithm to solve the following problem:

Given a set of time-stamped communications that
- Identify the communicators
- Have text in a possibly unknown language
- Involve lots of people, mostly of no interest
- Involve a small proportion of conspirators

Identify the conspirators and their relationships (command/reporting) while minimizing information intrusion

Conventional social network analysis only provides unhelpful "hairballs" such as the following, taken from simulated data logs from a scenario created for the Department of Defense:
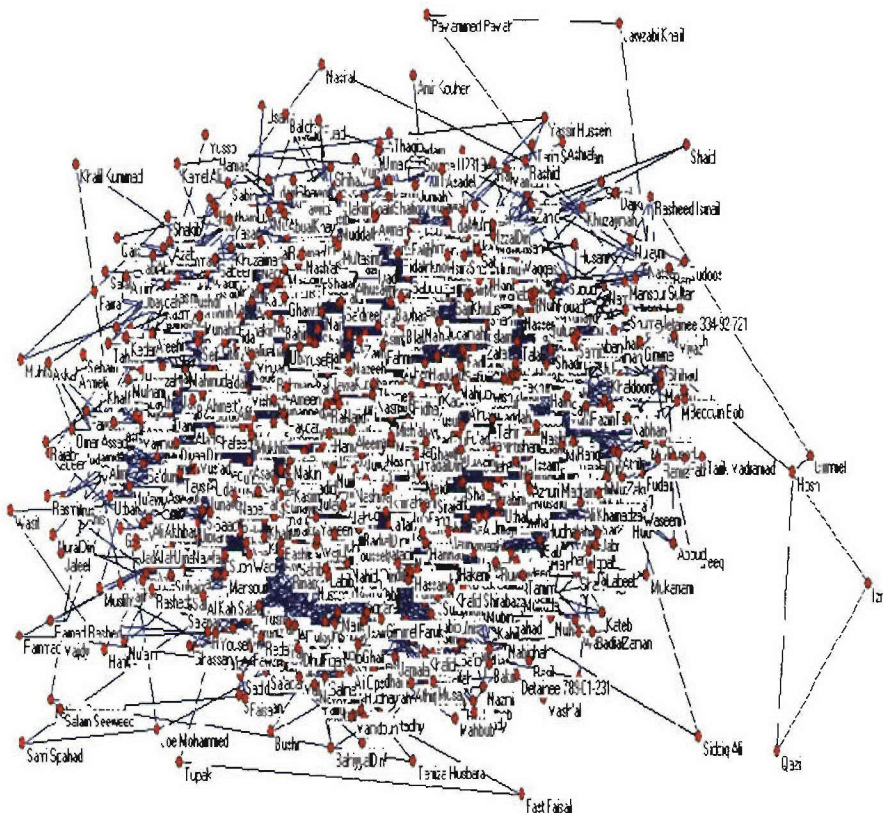
In this scenario, only 66 of about 1000 communicators are conspirators. There are more than 2000 messages.

Our algorithms, which uses only time ordering and probability measures extracted from frequency of communication, find about a third of the conspirators, and correctly links them in sub groups. Slightly more than 50% of the names returned are false positives.
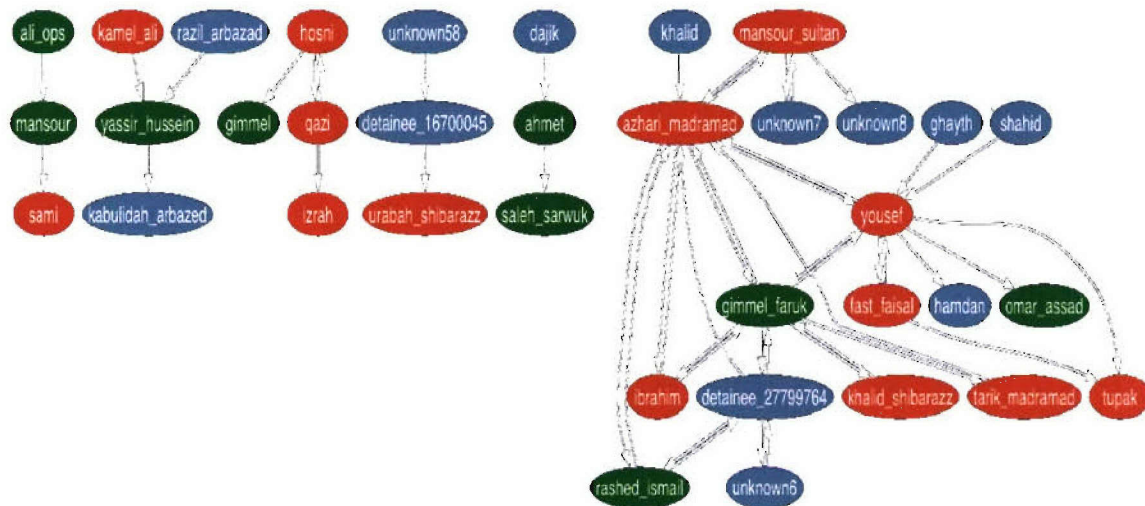
- 33% of known bad guys identified as part of a command structure
- Green = known leaders Red = known bad guy, Blue = others mis-identified

Publications, Awards, and Patents

Peer Reviewed Journal Articles:

Danks, D. "Psychological Theories of Categorization as Probabilistic Graphical Models," *Journal of Mathematical Psychology*, submitted.

Kyburg, Henry E. Jr. and Teng, Choh Man. "Nonmonotonic logic and statistical inference,"
Computational Intelligence, pages 26-51, 2006.

Kyburg, Henry E. Jr., Teng, Choh Man and Wheeler, Gregory. "Conditionals and consequences,"
Journal of Applied Logic, in press.

Book Chapters:

Glymour, C., Gerdes, D. and J. Ramsey, "Who Is Calling?" in A. Kott, ed., *Asymmetrical Warfare*, in press.

Kyburg, Henry E. Jr. and Teng, Choh Man, "Randomization and uncertain inference," in *Modern Information Processing: From Theory to Applications*, Bernadette Bouchon-Meunier, Giulianella Coletti and Ronald R. Yager, editors, Elsevier, pages 61-72, 2006.

Technology Transfer

A course was given in the summer of 2006 to Department of Defense personnel including details of the algorithms and applications outlined here on extracting network

information. A JAVA implementation of two algorithms is being made available to an agency of the DOD.

TRUSTWORTHY AGENTS THROUGH A MORE ADEQUATE THEORY AND IMPLEMENTATION FOR ADJUSTABLE AUTONOMY

Scientific and Technical Objectives

Highly effective teams must appropriately trade off authority and responsibility among various team members (humans, robots, software agents) as they coordinate joint activity. In contrast to typical adjustable autonomy mechanisms that rely on coarse-grained mode setting, we aim to develop mechanisms that will allow us to demonstrate the benefits of 'disciplined initiative,' namely, automatically adjusting autonomy and system initiative along multiple fine-grained policy-bounded dimensions (e.g., permissions, obligations, capabilities) to minimize the hazards of rigid "modes" and to provide greater team resilience for contingencies (e.g., a partially-disabled team member).

Approach

To support adjustable autonomy in our teamwork-oriented infrastructure, we are developing a component named Kaa (KAoS adjustable autonomy). Assistance from Kaa in making limited adjustable autonomy decisions might typically be required when it is anticipated that the current configuration of policies has led to or is likely to lead to poor performance or failure, and when there is no set of competent and authorized humans available to make the decisions themselves. Ultimately, it is a matter of expected utility: the utility of making some kind of change vs. the utility of maintaining the status quo.

Kaa uses decision-theoretic algorithms to determine what if any changes should be made in agent autonomy. When invoked, Kaa first compares the utility of various adjustment options (e.g., increases or decreases in permissions and obligations, acquisition of capabilities, proactive changes to the situation to allow new possibilities), and then—if a change in the status quo is warranted—takes action to implement the recommended alternative.

Our first version of Kaa used static influence diagram models which did not vary across situation contexts. This approach was inflexible and inefficient. One of our major goals for this year's research was to leverage the power of the logical representation and reasoning mechanisms in our KAoS policy services framework to construct an appropriate probabilistic influence diagram model for the situation at hand on the fly, consistent with the rationale first given by Szolovits and Pauker in 1978:

> When... complex problems need to be addressed... then... probabilistic models are necessary. The essential key to their correct use is that they must be applied in

a limited problem domain where their assumptions can be accepted with confidence. Thus, it is the role of categorical methods to discover what the central problem is and to limit it as strongly as possible; only then are probabilistic techniques appropriate for its solution.
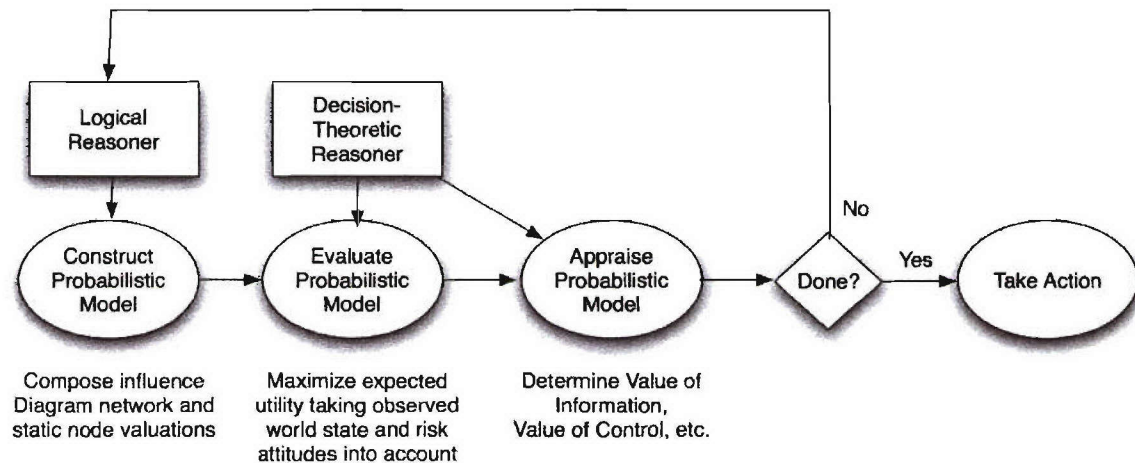
Our aim in extending Kaa in this fashion (shown in diagrammatic form above) is to move from a situation where a different point solution for adjustable autonomy is required for each application toward the goal where we can create and validate a general model for adjustable autonomy that can work in tandem with KAoS teamwork policies across a wide spectrum of domains. Moving beyond the application-specific influence diagrams we have constructed for the initial prototype, we propose to represent the specific implications of our general model of adjustable autonomy in skeletal knowledge bases *(influence diagram templates)* of probabilistic information, alternatives, and preferences that can be reused for particular classes of decisions. Portions of this knowledge base would then be combined with application-specific and situation-specific information, alternatives, and preferences obtained at runtime.
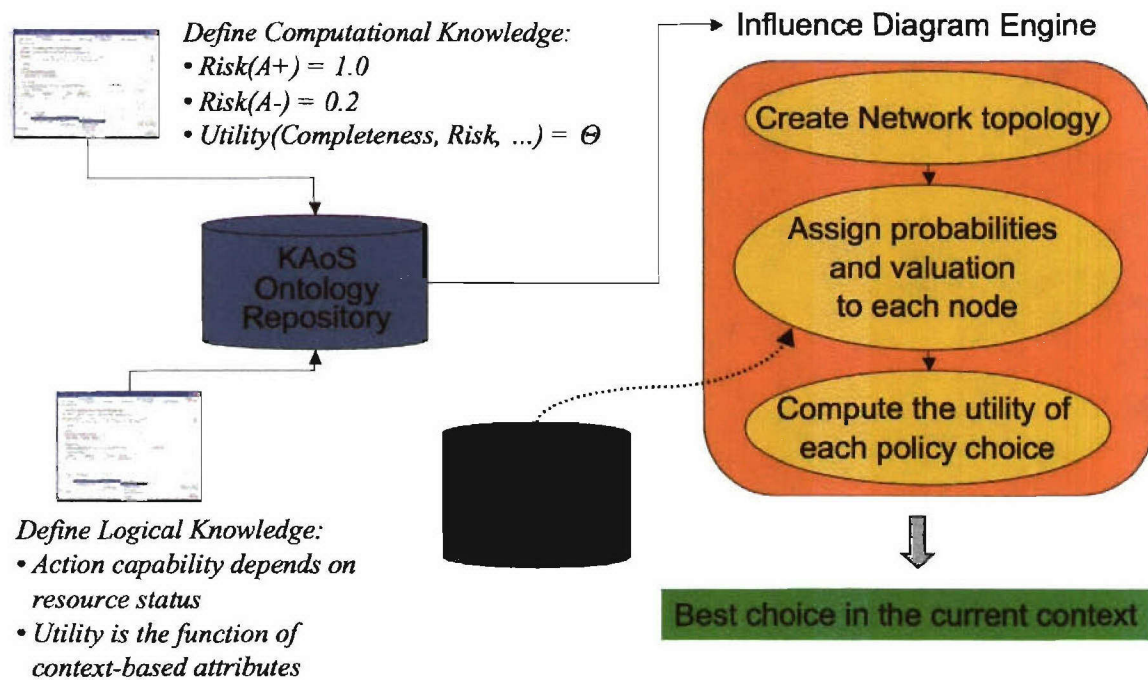
Concise Progress Statement

We developed initial KAoS ontologies and reasoning mechanisms to allow us to represent and construct influence diagram models on the fly. In addition we have begun work on generic ontologies of team recovery alternatives and of regulatory concepts to help generate and reason about candidate actions that can be fed to the influence diagram model. We have constructed a demonstration of this capability that will serve as the basis for additional experimentation in the context of a large human-robotic teamwork exercise in the first half of 2007.

Expanded Description of Accomplishments

The basic operation of the system is illustrated below. KAoS maintains situation awareness by subscribing to relevant sensor and other information feeds relevant to the joint activity. When the KAoS becomes aware of a failed or potentially failed action,

creates an influence diagram network for Kaa populated with appropriate parameters from the knowledge base and the observed world state. The decision-theoretic engine in Kaa then computes the expected utility of various alternatives (e.g., modify some aspect of the situation, add capabilities, lift negative authorizations, renege or delegate obligations) and selects the best alternative consistent with situation constraints. Users can specify which actions Kaa can be allowed to adjust and which it must leave to human judgment.

Define Computational Knowledge:
- *Risk(A+) = 1.0*
- *Risk(A-) = 0.2*
- *Utility(Completeness, Risk, ...) = Θ*

Influence Diagram Engine

Create Network topology

Assign probabilities and valuation to each node

Compute the utility of each policy choice

KAoS Ontology Repository

Define Logical Knowledge:
- *Action capability depends on resource status*
- *Utility is the function of context-based attributes*

Best choice in the current context

Publications, Awards, and Patents

Books or Book Chapters

Bradshaw, J. M., Jung, H., Kulkarni, S., Johnson, M., Feltovich, P., Allen, J., Bunch, L., Chambers, N., Galescu, L., Jeffers, R., Suri, N., Taysom, W., & Uszok, A. (2005). Toward trustworthy adjustable autonomy in KAoS. In R. Falcone *et al.* (Eds.), *Trusting Agents for Trustworthy Electronic Societies*. LNAI. Berlin: Springer.

Feltovich, P. J., Bradshaw, J. M., Clancey, W. J., and Johnson, M. (2006). We regulate to coordinate: Limits to Human and Machine Joint Activity. To appear in edited book.

Abstracts/Presentations/Posters/Conference

Johnson, M., Bradshaw, J. M., Feltovich, P., Jeffers, R., Jung, H. & Uszok, A. (2006). A semantically-rich policy-based approach to robot control. Proceedings of the Third International Conference on Informatics in Control, Automation, and Robotics (ICINCO

2006), Setúbal, Portugal, 1-5 August.

Feltovich, P. & Bradshaw, J. M. (2006). We regulate to coordinate: Human and machine joint activity. Invited presentation, 2006 Benjamin Franklin Medal in Computer and Cognitive Science Award Symposium for Donald A. Norman, Philadelphia, PA: University of Pennsylvania, 27 April.

Bradshaw, J. M. (2006). Characterizing joint activity in human-agent-robot teamwork. Invited Lecture, King Fahd University of Petroleum and Minerals, Dammam, Saudi Arabia, 27 May.

Feltovich, P. J., Bradshaw, J. M., Clancey, W. J., and Johnson, M. (2006). We regulate to coordinate: Limits to Human and Machine Joint Activity. Invited paper, Proceedings of ESAW 2006, 6-8 September, Dublin.

Rehák, M., Gregor, M., Pechoucek, M., and Bradshaw, J. M. (2006). Representing context for multiagent trust modeling. Proceedings of the International Conference on Intelligent Agent Technology, Hong Kong, China, December.

Technology Transfer

We will use this capability as part of an ONR-funded Coordinated Operations project to demonstrate multi human-robot coordination in a reconnaissance scenario in a port facility. The Air Force Research Laboratory has recently funded an SBIR to allow us to mature this capability in the context of risk-adaptive access control in the Global Information Grid. Additionally, the Army Research Labs has expressed interest in this capability and plans to make use of it in a Blue-force tracking scenario in 2007.

EXOSKELETONS FOR HUMAN PERFORMANCE ENHANCEMENT

Scientific and Technical Objectives

Our objective for this project was to expand our previous research on exoskeletons, including improved man-machine attachments, algorithms for human intention detection, control algorithms for locomotion, and improved actuation. Towards these ends, we designed and built two exoskeleton prototypes: The PISCES underwater exoskeleton, and a Powered Climbing Suit.

Approach

The goal of an exoskeleton is to provide the user enhanced performance by increasing the wearer's strength, endurance, and/or speed enabling them to perform tasks that they previously could not perform. At the same time, the exoskeleton should not impede the user's natural motion, nor interfere with sensory or cognitive capabilities. The

exoskeleton should provide a natural, intuitive, transparent interface such that the user feels as if the exoskeleton is a true extension of his/her body rather than something that the user is driving. These considerations were all taken into account in the development of the two exoskeletons.

Concise Progress Summary

We focused our efforts on two robotic exoskeleton projects: one for swimming, and one for climbing. PISCES, the swimming exoskeleton was constructed and tested in a shallow pool. The fit on the user was comfortable, and the device survived being submerged in water. In terms of performance, there was limited enhancement due to undersized actuators. This problem is being corrected with an identical form factor actuator but difference electro-mechanical properties. The other exoskeleton that was developed was a Powered Climbing Suit prototype, which we designed, built, and tested. The interface was a simple handgrip that user pulled up or push down on to raise or lower himself. With this device the user could perform one handed chin ups on a test bar with very little effort.

Expanded Description of Accomplishments

PISCES, an underwater swimming exoskeleton, was designed to increase the speed and endurance of a human swimming underwater. The exoskeleton has been tested in the water for fit, comfort, and range of motion. The force measurement system, the electronic system, and the actuators have been tested underwater for an extended period of operation. Unfortunately, with the motors, amplifiers, and gear trains that we selected, the swimming abilities of the user were not extended. We are currently waiting for new components that will have a factor of 3 power increase, which should be sufficient for capability enhancement.

A climbing suit exoskeleton was designed, built, and tested. This device featured a preliminary user handgrip interface. One end of the interface attached to the cable of the device and the other end had a hook that was attached to a fixed point on the ceiling. Built into the handgrip interface was a load cell that measured the force the user was applying. We tested the device by having the user pull and push on the handgrip to raise and lower himself.
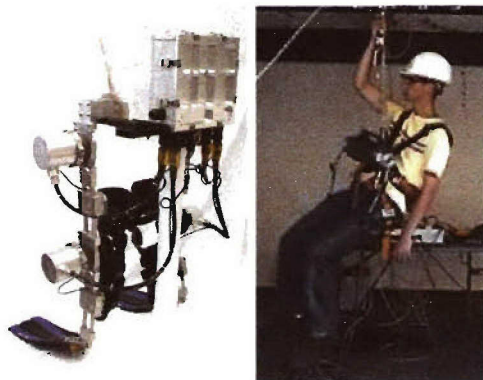

Figure 1: The picture on the left is PISCES, an underwater exoskeleton. The picture on the right shows a user wearing a climbing suit exoskeleton and raising and lowering himself using very little force with his right arm.

Publications, Awards, and Patents

<u>Peer-Reviewed Journal Articles</u>

Neuhaus, P. and, Pratt, J, "Performance Improving Self Contained Exoskeleton for Swimming (PISCES)," In Preparation, 2006.